Diverse SMR Siting in the UK

By **Mike Crawforth**, **Neil Harman**, **Chloe Howard**, **David Price**

SUMMARY

- Challenges and opportunities in relation to SMR siting
- Co-generation applications
- Alternative financing models
- Considerations for siting next to industry
- Applying the UK semi-urban criteria for five of the identified UK industrial clusters

1. INTRODUCTION

Small Modular Reactors (SMRs) are generally defined by power output and although the size varies, there is a consensus in literature that anything below 500 MWe may be interpreted as an SMR. Global interest in SMR deployment and use is gradually increasing due to the siting flexibility and use case versatility that smaller, modularised plants claim to provide, in comparison to large GWe scale nuclear facilities. In addition, the potential cost benefits of offsite construction and fleet scale deployment are further increasing the pool of viable use cases. These claims are linked to the potential of multi-module deployment, co-generation configurations and enhanced load following capabilities, as well as assumptions that siting constraints may lessen on the basis of inherent safety embedded into designs such as reduced core inventories [1].

Although SMRs can provide baseload electricity to the grid, their potential for enhanced siting flexibility supports a wider interest in co-generation applications such as district heating or the production of hydrogen and its derivatives. Such siting flexibility is potentially enabled by:

- **Reduced cooling requirements** - the smaller size of SMR designs compared to GWe scale nuclear, along with the greater thermodynamic efficiency of higher temperature designs, all serve to reduce the total cooling demand for the power plants; in addition, most SMR technology providers are developing indirect and closed loop cooling solutions to reduce the requirement for cooling water even further, maximising their siting potential.
- **Transportable scale** - owing to the "plug and play" nature of proposed road transportable nuclear modules, additional uses open up for the category of micro-reactors such as remote location deployment and emergency power requirements [1].

This article highlights the challenges and opportunities in relation to SMR siting specifically in the UK. In general UK siting requirements have been reviewed as well as consideration for specific hazards that may be introduced when siting near industrial clusters.

The new National Policy Statement (EN-7) [2] released for further consultation at the time of going to press is a step towards enabling wider options for nuclear power deployments, including the applications considered for SMRs.

2. CO-GENERATION APPLICATIONS

Diverse siting arrangements of SMRs will support efficient and flexible deployment by reducing the distance from both existing industrial presence and existing grid energy infrastructure. The increasing energy demands in the UK, and globally, in parallel with the world climate crisis is exacerbating the need for fast deployment of low carbon energy sources such as SMRs. When considering SMR or Advanced Modular Reactor (AMR) (based on non-light water reactor technology) deployment the specific technology chosen will be based on maximising the economic conditions for a given use case and deployment location. The IAEA Advanced Reactor Information System (ARIS) database [3] holds information on AMRs in development, including designs that would be classified as SMRs; the outlet temperatures of these designs are shown in Figure 1.

Various SMR and AMR designs are being developed to meet the thermal demands of hard to abate sectors such as shipping,

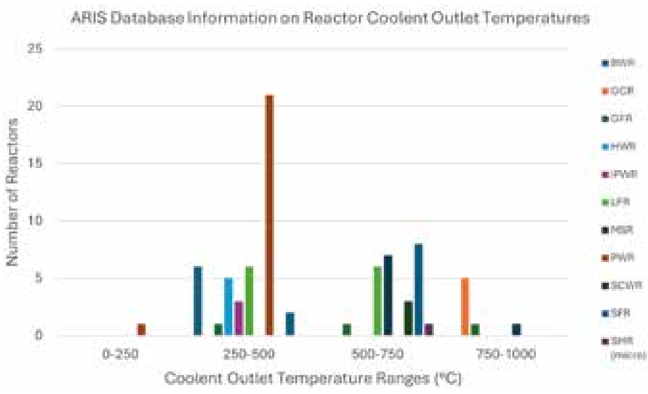


FIGURE 1 - ARIS Database of Outlet Temperatures (Data collected August 2024, [3])

aviation, iron and steel, chemicals and petrochemicals. As seen in Figure 2 reaching temperatures in excess of 1000°C cannot be done solely on the use of direct reactor heat no matter what the technology and as such, where such a use case cannot be electrified, many reactor vendors are suggesting the use of SMRs/AMRs for hydrogen production as a route to decarbonisation. The hydrogen produced can be used as fuel to reach the desired process temperature required for high temperature industries currently based on natural gas combustion such as steel manufacture.

This gives three methods through which SMRs can interact with the thermal power markets to address decarbonisation opportunities across the whole temperature range: provision of direct thermal power, provision of low carbon electricity combined with the electrification of heat or the provision of low carbon hydrogen and its subsequent combustion.

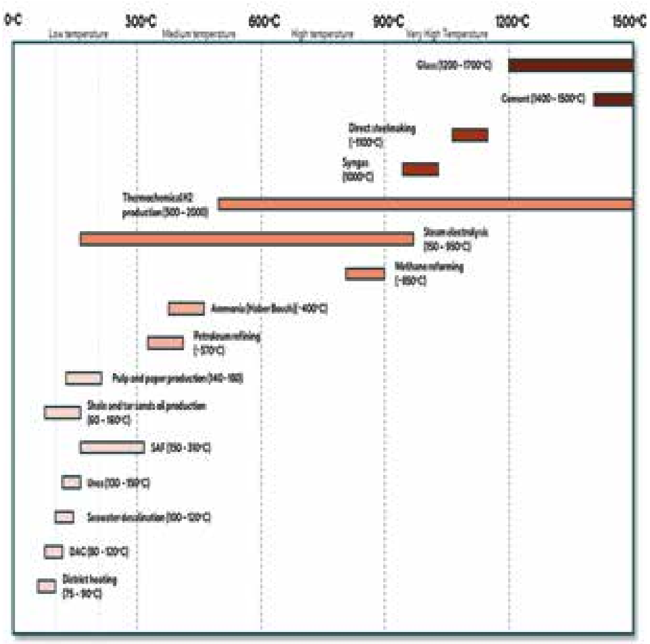


FIGURE 2- Comparison of SMR/AMR Designs and Industry Temperatures. Illustration of the temperature requirements for a range of industrial use cases - Rolls-Royce SMR

3. ALTERNATIVE FINANCING MODELS

The ability to co-locate with end users has the potential to drive innovative financing arrangements for nuclear power deployment. The emergence of use cases for highly reliable, off-grid power supply (e.g. data centres) at the scale of SMR power outputs is driving interest in direct coupling between SMR deployments and such use cases. Current financing options for new nuclear in the UK include using a Contract for Difference (CfD) or a Regulated Asset Base (RAB) model – both requiring a level of risk allocation with the government. An alternative approach is the Mankala model, successfully deployed in several Finnish infrastructure projects including large scale nuclear. In summary the Mankala model is a shared ownership model, typically with a collection of industrial end users (or utilities) that cooperate to share the risk of nuclear deployment across several balance sheets, to enable collective benefit of long-term energy assurance and price stability. The most notable example for nuclear is the company TVO which has overseen the construction and operation of all three units at Olkiluoto under a Mankala model with a wide variety of owners.

An interesting variant of Mankala is the SaHo model [4] proposed by the Polish government to implement nuclear power development plans, which could possibly be used in other countries and in sectors requiring high capital expenditure. The model depends on the state providing initial funding and then gradually selling its stake to industrial consumers or utilities (see Figure 3).

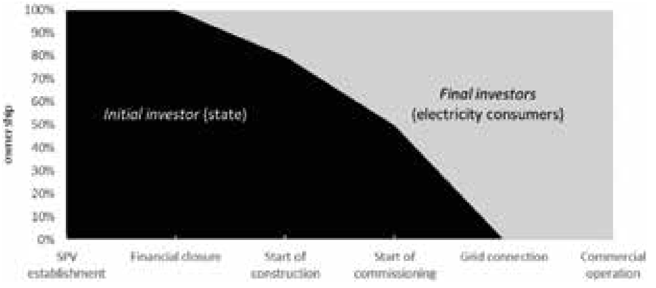


FIGURE 3: The SaHo share ownership model (Figure 3 in [4])

4. INDUSTRIAL CLUSTERS IN THE UK

The UK's Industrial Decarbonisation Strategy identified the six largest industrial clusters based on carbon dioxide emissions, as shown in Table 1 [5]. These areas are prime examples of the UK's need for centralised low carbon energy in terms of electrical power and process heat. As shown in Figure 2, varying process temperatures will be needed to decarbonise the sectors represented in the UK industrial clusters. Co-locating an SMR for direct electrical and thermal energy provision combined with the potential for on-site hydrogen production creates a more robust energy infrastructure taking pressure off an increasingly constrained national grid. Grid capacity has been recognised as a key limiting factor to industrial decarbonisation, therefore future nuclear siting criteria must look towards optimising siting in a way that can minimise grid constraints [6].

Cluster Location	CO_2 Emissions ($MtCO_2e/yr$)	Largest Contributing Industries
Grangemouth	5.0	Chemicals, Refining
Humberside	10.0	Iron/Steel, Refining
Merseyside (Elsmere Port)	5.0	Chemicals, Refining
South Wales (Port Talbot)	8.9	Iron/Steel, Refining
Southampton (Solent)	3.2	Chemicals, Refining
Teesside	3.9	Chemicals, Iron/Steel

TABLE 1 - UK industrial clusters and their CO_2 emissions (Adapted from [5])

5. ASSESSMENT AGAINST SITING CRITERIA IN THE UK

The national policy statement recently put out for public consultation for new nuclear generation in the UK [7] states that the EN-6 siting criteria remain relevant to new GWe, SMR and AMR technologies. The policy statement recognised that diverse siting arrangements of advanced nuclear technologies closer to denser populations may be of benefit when industrial requirements are considered, but at the present time the semi-urban demographic criterion will be kept consistent for new deployment.

The Office for Nuclear Regulation (ONR) describes the demographic (semi-urban) criteria and formula to apply in NS-LUP-GD-001 'Land Use Planning and The Siting of Nuclear Installations' [8].

Application of these criteria in five potential industrial areas – Teesside (around the existing nuclear site of Hartlepool) and 4 other new sites identified above as industrial clusters excluding Grangemouth since there are currently no plans for nuclear new build in Scotland – was considered to see how restrictive these demographic criteria would be.

A 10 km square area in each cluster location was selected (15 km square for Humberside) and divided into 100 m x 100 m squares. ONR's formula was applied assuming a nuclear installation were constructed at the centre of each of the 100 m squares; the calculation for each 100 m x 100 m square involves:

- Drawing a 30 km radius circle around the site (100 m grid square centre).
- Forming a polar grid comprising 1 km rings and 5° sectors.
- Summing all residential population in each of the polar grid elements.
- Applying a distance weighting factor (as defined in NS-LUP-GD-001) so that population further from the centre counts less than that closer in; this reflects the dispersion of any radioactivity released into the atmosphere that would occur.
- Calculating the cumulative (from the centre out) weighted population in each polar grid element.
- Comparing the results with those for a similar calculation for a uniform population distribution (1000 people per km^2 all-round and 5000 people per km^2 in any 30° sector) and calculation of the ratio to give a Site Population Factor (SPF); there are screening criteria for 30° sectors (of the six possibilities made from 5° sectors) and the all-round population.
- The highest SPF for any of the polar grid elements is determined.
- An SPF >= 1 means a nuclear installation centred here would fail ONR's criteria.

The SPFs for each 100 m square grid element in the large square area are calculated and plotted for each of the potential sites – see images in Figure 4.

In the images in Figure 4, the green circles show the population at each postcode from the 2021 census which was the population data used to perform the calculations; the population data were obtained from the Office of National Statistics [9]. The coordinates for each post code were obtained from Ordnance Survey [10]; all the population for that post code is assumed to reside at these coordinates. Any square coloured light red or darker has an SPF >=1 (see scales on the maps) and therefore would fail the semi-urban criteria and be screened out as a potential location in that area. Areas uncoloured would pass and those in yellow have an SPF close to 1 but still pass.

The images in Figure 4 show that if the demographic criteria are applied as stated in NS-LUP-GD-001 [8], then each of the potential industrial areas would still have some potential site locations that would meet ONR's demographic criteria.

ONR's criteria are only screening values used to screen out clearly unsuitable sites; there may be other reasons to do with

FIGURE 4 - Site Population Factor (SPF) Evaluations for Selected UK Industrial Clusters

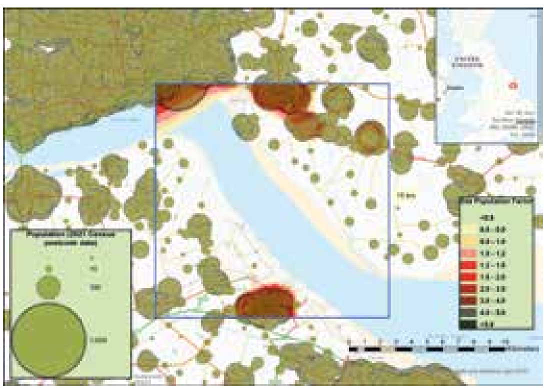
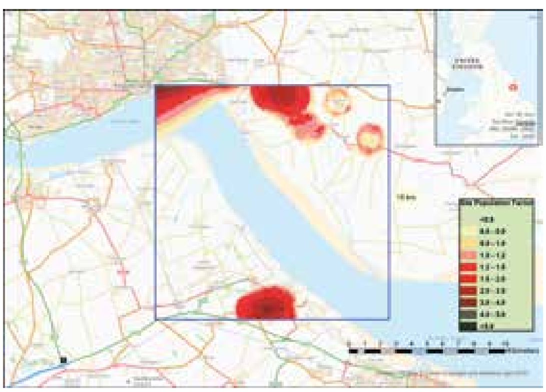
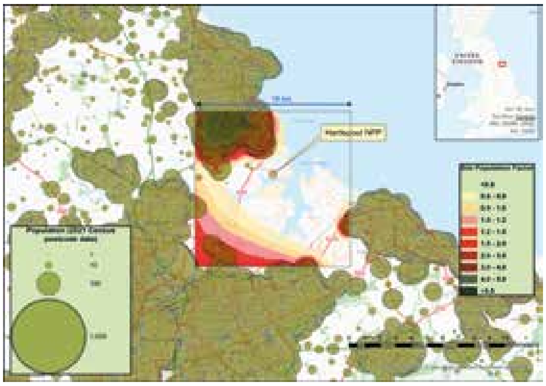
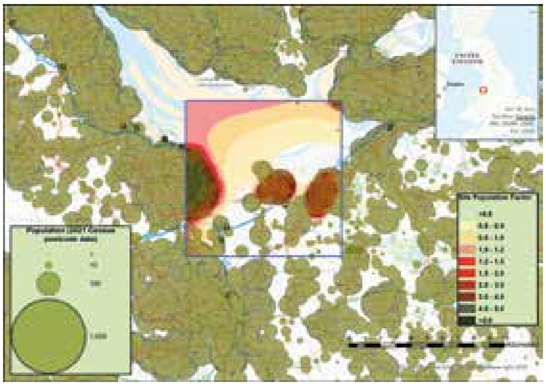
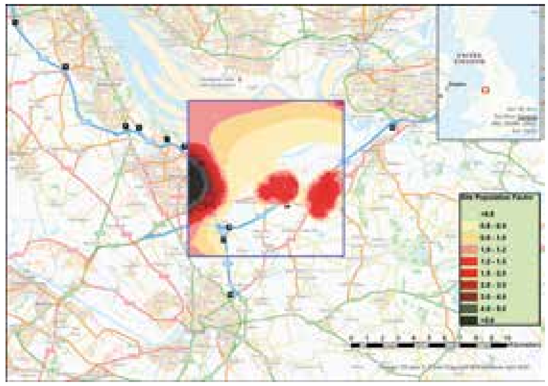
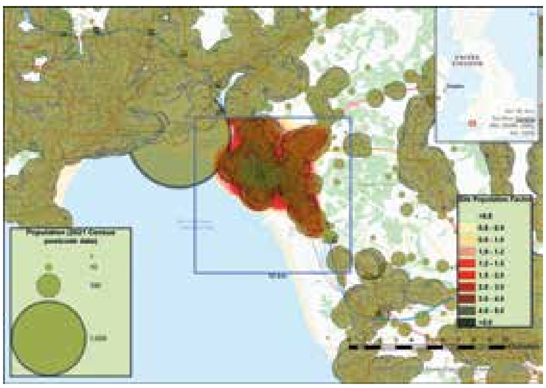
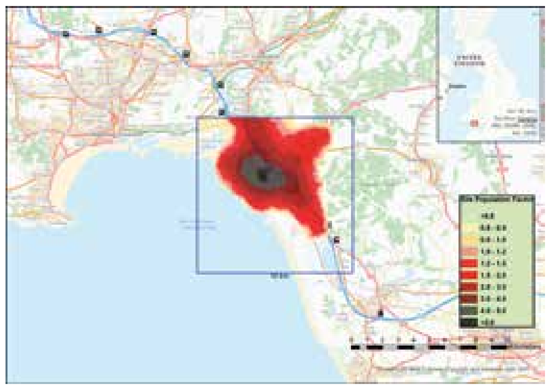
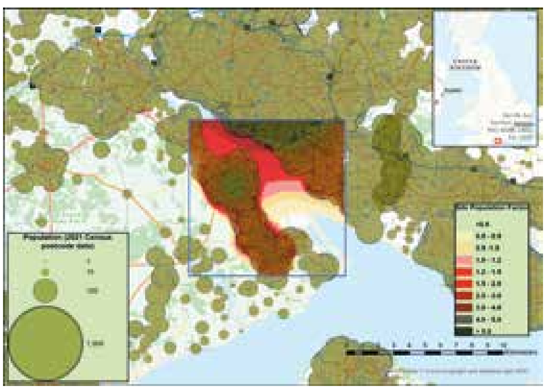
	Population at each Post Code & Site Population Factor	Site Population Factor only
Humberside		

FIGURE 4 - Site Population Factor (SPF) Evaluations for Selected UK Industrial Clusters (Cont.)

	Population at each Post Code & Site Population Factor	Site Population Factor only
Teesside		
Ellesmere Port		
Port Talbot		
Solent		

the population distribution – or other reasons some of which are discussed below – why the site might be unsuitable which would need to be investigated. For example, there may be physical barriers preventing or inhibiting evacuation or other emergency countermeasures. The census data is the residential population as assumed in [8] for the SPF calculation, but there will be a day-time working population (as can be seen on the maps by the buildings represented on the maps with no census population – for example at Teesside) that would also need to be considered in any emergency plan for the site along with any special groups such as schools, care homes, hospitals etc., or other temporary groups.

The images in Figure 4 show that the population density tends to rise sharply towards town centres and therefore that any relaxation in the demographic criteria would be unlikely to result in a significant increase in the area of land available. In other words, if the same basic formulation were kept but the population density limits were increased from the current levels of 1000 people per km^2 all-round and 5000 people per km^2 in any 30° sector, the current situation regarding the land available for SMR siting would not change significantly.

6. SITING NEXT TO INDUSTRY

Taking into consideration the semi-urban demographic criterion in the UK, there are possibilities to site near industrial locations, this results in additional challenges such as the industrial hazards that are now imposed on a nuclear facility. The UK has a history of industrial uses of nuclear power when considering aluminium smelters based in North Wales and Scotland in which lessons learned from ownership models and investment decisions can be taken [11]. Although novel in some respects, many countries have started research into the possible cogeneration capabilities that SMRs or larger plants can provide. Safety considerations in general between nuclear and chemical/industrial plants are fundamentally different. Within nuclear operations a key safety philosophy is the confinement of radioactive materials within the plant to reduce the likelihood of a release event; however within the chemical industry confining materials may have a negative impact on safety especially considering the accumulation of potentially explosive material such as hydrogen [12,13]. Ensuring no cross contamination of processes will be a vital element in the potential deployment of co-generation SMRs and in particular, the examination of the radiological implications of joint systems and its relationship to the nuclear liability of the site licensee. Globally, many countries are considering the possibility of nuclear hydrogen production and with that comes additional challenges into the safety philosophy of such a facility and the hazard considerations that now need to be evaluated.

Recent work has highlighted the potential for nuclear derived hydrogen including the utilisation of SMRs and hydrogen production to add flexibility into an energy system whilst improving the underlying profitability of SMR deployment [14].

The production of clean hydrogen at scale is a developing industry with many challenges, even without linking to nuclear power sources. However, the Nine Mile Point NPP in the US is already producing hydrogen via a Proton Exchange Membrane (PEM) electrolyser for onsite hydrogen needs including, cooling of the main electric generator and for injection into the reactor coolant system to protect against intergranular stress corrosion cracking [15]. Although examples like this are proof of concept for nuclear hydrogen production, there are a number of hazards that need to be assessed as part of hydrogen being present at a nuclear facility such as, hydrogen explosions, hydrogen piping breaks and electrical transients due to hydrogen plant production trips [16].

Within the UK, the United Kingdom National Nuclear Laboratory has advocated for the role nuclear can play in unlocking the hydrogen economy to support a net zero future. Whilst appreciating the differences in safety philosophies of a nuclear and hydrogen production plant some potential mitigation measures have been identified in [13] as:

- Increasing the distance between a nuclear and electrolysis facility.
- Utilising a raised land barrier between plants.
- Implementing blast protection near the plants.
- Situating the nuclear reactor and key safety systems underground or the electrolysis facility construction below ground level.

Within the UK's safety framework between the ONR and the Health and Safety Executive, there is an overlap concerning radiological safety and chemical safety when considering the assessment of Emergency Planning Zones (EPZ) based on hazard consequence assessment, as discussed in [13]. However, as previously stated, fundamentals within the safety philosophies of these industries may differ when referring to the requirement of confinement and dispersion. Additionally for co-generation capabilities to be realised in the UK, the assessment of a nuclear facility to perform this function would need to be captured in the licensing process. Regulations and oversight programs for co-generation uses would need to be developed [11]. Public perception of a cogeneration facility will also be a vital element in enabling or hindering its potential deployment in the UK. Ensuring wider public knowledge of the benefits that can be brought through using nuclear power to bring new industry into a region, including the decarbonisation of the local economy will be necessary.

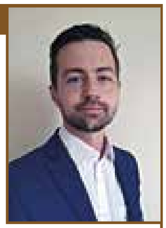
For optimising the siting of SMR assets, a balance must be found between minimising the distance to the ultimate energy consumer whilst maximising site suitability. For the transport of electricity, it is possible to construct short to medium distance high voltage transmission with a relative degree of ease, notwithstanding the current backlog in capacity. The transmission of high temperature steam is however more difficult, with planning issues concerning above ground steam pipes likely to prove the more limiting constraint than economic or technical considerations. The transport of hydrogen or synthetic fuels present other constraints, the existing gas transmission network or Exolum fuel pipelines present possible solutions for enabling offtake, however, these do not always coincide with suitable locations for SMR deployment. The establishment of large-scale transportation infrastructure is a matter of national investment to enable the energy transition and consideration should be given to how SMR flexibility could minimise the total system constraints across full energy system.

7. CONCLUDING REMARKS

This paper discussed SMR co-generation applications, alternative financing models, siting next to industry considerations and assessed the potential impact the UK's semi-urban demographic criterion may have on siting SMRs near identified UK industrial clusters. As shown in Figure 4, when the current demographic criteria are applied each of the potential industrial areas would still have some potential site locations that would meet ONR's demographic criteria. Additionally, as the population density tends to rise sharply towards town centres any relaxation in the demographic criteria would be unlikely to result in a significant increase in the area of land available for SMR deployment. As mentioned in preceding sections, there are other evaluations that would need to be made to ensure suitable sites for SMR deployment which were out with the scope of this evaluation.

In summary there are potential sites in the UK that can enable optimised siting near industry if enablers are met such as community acceptance of the deployment, agreed approaches to safety analysis that industrial hazards may impose on the nuclear facility and national investment in transportation infrastructure to support potential use cases of SMRs out with electricity production.

MIKE CRAWFORTH



Mike is the Business Development Manager for Rolls-Royce SMR, utilising a wealth of experience in the nuclear industry to help meet the twin challenges of decarbonisation and energy security. Specialising in technology introduction programmes, Mike has worked across the breadth of the nuclear industry including the UK's submarine programme, decommissioning, the development of a micro reactor and the genesis of the UK space nuclear programme.

Mike, now with Rolls-Royce SMR, is working with utilities, energy users and policy makers to develop new scalable models to deploy nuclear solutions into the energy ecosystems of tomorrow, driving down the system costs of the energy transition.

NEIL HARMAN

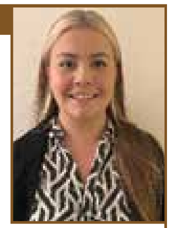
Neil is a consultant with Amentum working mainly supporting the licensing of new nuclear power plants including SMRs and AMRs in the UK and overseas in technical areas such as radiological consequence assessment including Level 3 PSA (Probabilistic Safety Analysis) and emergency preparedness and response.

He has contributed to a number of IAEA Safety Standards and other IAEA documents and regularly participates as an External Expert on IAEA Missions including SEED (Site and External Event Design) Review Missions where the suitability of potential sites as far as the feasibility of the emergency pan is considered.

Email: neil.harman@global.amentum.com

LinkedIn: https://www.linkedin.com/in/neil-harman-1928a62a/

CHLOE HOWARD

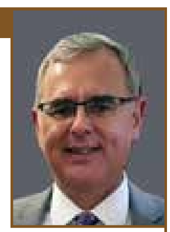


Chloe is a Nuclear consultant with Jensen Hughes working mainly on Small Modular Reactor (SMR) and New + Advanced Reactor deployment projects supporting nuclear safety, site licensing, technology feasibility studies and capacity building for clients. Additionally, Chloe is involved in advanced nuclear technology risk research covering topics such as risk metrics and passive safety system requirements for use in Probabilistic Safety Analysis (PSA).

Email: chloe.howard@jensenhughes.com

LinkedIn: www.linkedin.com/in/chloe-h-116162151

DAVID PRICE



David is the Director of New Build for NUVIA, working across all the major fission and fusion projects in the UK including Hinkley Point C, Sizewell C, Rolls-Royce SMR and UKAEA. NUVIA is a specialist nuclear engineering and construction organisation, part of the world-wide VINCI Group.

David has worked in the nuclear industry for 20 years, across a wide range of clients which encompass the decommissioning, new build and defence sectors.

David contributes to several committees in both the fusion and fission sectors.

E: david.price@nuvia.com

LI: https://www.linkedin.com/in/davidprice1961/

ABOUT THE SMR SPECIAL INTEREST GROUP

SIGs

SMALL MODULAR REACTORS

The Small Modular Reactor Special Interest Group (SMR SIG) supports the development and deployment of small modular reactors, being any nuclear reactor technology to be deployed at sub-gigawatt scales with a modular build approach, in the UK.

It is primarily concerned with issues relating to: build methodology, licensing, financing, co-generation, Fleet operation and international deployment.

The SMR SIG brings together relevant experts and interested parties to develop thought leadership on matters within its scope of interest. In this way, the SIG can provide advice to both the public and private sectors on how to maximise the potential of SMRs and overcome the associated challenges.

Visit **nuclearinst.com/SMR-SIG** or contact **smrsig@nuclearinst.com**

REFERENCES

[1] NEA (2021), Small Modular Reactors: Challenges and Opportunities, OECD Publishing, Paris

[2] Draft National Policy Statement for nuclear energy generation (EN-7): new consultation, and response to earlier consultation. Available at https://www.gov.uk/government/consultations/draft-national-policy-statement-for-nuclear-energy-generation-en-7

[3] Aris, Advanced Reactor Information System. Available at: https://aris.iaea.org/TechnicalData/ (Accessed: 09 January 2025).

[4] Role of the state in implementation of strategic investment projects: The SaHo Model for nuclear power, Sawicki, Łukasz, and Bożena Horbaczewska, International Journal of Management and Economics, vol. 57, no. 4, Sciendo, 2021, pp. 343-359. https://doi.org/10.2478/ijme-2021-0020

[5] Industrial Decarbonisation Strategy, March 2021. Available at https://assets.publishing.service.gov.uk/media/6051cd04e90e07527f645f1e/Industrial_Decarbonisation_Strategy_March_2021.pdf

[6] National Wealth Fund Taskforce, Green Finance Institute, Interim Sector Analysis Appendix, July 2024, Available at https://www.greenfinanceinstitute.com/wp-content/uploads/2024/07/20240703_NWF-Taskforce_Sector-Analysis.pdf

[7] A National Policy Statement for new nuclear power generation, Consultation on the new approach to siting beyond 2025, Department for Energy Security & Net Zero, January 2024, Available at https://assets.publishing.service.gov.uk/media/659fa3313308d2000d1fbe04/nps-new-nuclear-siting-consultation.pdf

[8] Land use planning and the siting of nuclear installations, Office for Nuclear Regulation (ONR), ONR Guidance Document, NS-LUP-GD-001 (DOCX), November 2024, Available at https://www.onr.org.uk/our-work/what-we-regulate/other-regulationslegislations/land-use-planning/

[9] Postcode resident and household estimates, England and Wales: Census 2021, Office for National Statistics, Available at https://www.nomisweb.co.uk/sources/census_2021_pc

[10] Code-Point Open, Ordnance Survey, Available at https://osdatahub.os.uk/downloads/open/CodePointOpen

[11] Nuclear cogeneration : civil nuclear energy in a low-carbon future, The Royal Society, Issued: October 2020 DES7116, ISBN: 978-1-78252-494-6, Available at https://royalsociety.org/-/media/policy/projects/nuclear-cogeneration/2020-10-7-nuclear-cogeneration-policy-briefing.pdf#:~:text=Nuclear%20energy%20has%20the%20potential%20to%20help

[12] Safety concept of nuclear cogeneration of hydrogen and electricity, Verfondern, Karl, et al., International Journal of Hydrogen Energy 42.11 (2017): 7551-7559

[13] Nuclear Enabled Hydrogen Co-Generation: Safety and Regulatory Insight, National Nuclear Laboratory (NNL), International Conference on Hydrogen Safety, September 2023, Chapman, H. and Lawton, S. Available at https://hysafe.info/uploads/2023_presentations/20-09/S309B/01_143_Chapman.pdf

[14] SMRs cost-effective in hydrogen production, study finds, World nuclear news (Wnn), May 2024, Available at https://www.world-nuclear-news.org/Articles/SMRs-cost-effective-in-hydrogen-production,-study

[15] Delivering the Nuclear Promise Top Innovative Practice, Demonstration of Clean Hydrogen Production at Nine Mile Point, December 2023, Available at https://www.nei.org/CorporateSite/media/filefolder/resources/delivering-nuclear-promise/2023/DNP-TIP-2023-04-Nine-Mile-Point-Clean-Hydrogen-Production.pdf

[16] Considerations for Producing Hydrogen with an Existing Nuclear Power Plant, Electric Power Research Institute (EPRI), 3002025730, November 2022